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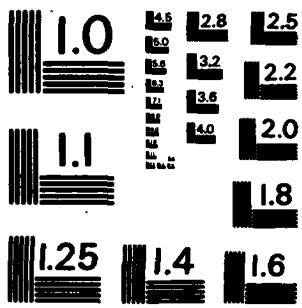


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DEPARTMENT OF DEFENCE

ROYAL AUSTRALIAN AIR FORCE

AIRCRAFT RESEARCH AND DEVELOPMENT UNIT

EDINBURGH, SOUTH AUSTRALIA

TECHNICAL NOTE GENERAL 19

# A DEVICE FOR MEASUREMENT OF CONTROL COLUMN FORCES IN AIRCRAFT





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A device is described which is incorporated within a pilot's flying glove to measure forces exerted by the pilot on the control column of an aircraft during flight tests.

This device enables a test pilot to obtain a quantitative measurement, rather than a subjective estimate, of 'stick' force which, together with the observation of normal load factor and variation, in airspeed, enables the calculation of parameters such as 'stick force per g' and 'stick force gradient' in non-manoeuvring flight.

This device is independent of aircraft-integral flight test instrumentation and can thus be used in any aircraft being flight tested.


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AIRCRAFT RESEARCH AND DEVELOPMENT UNIT

A DEVICE FOR MEASUREMENT OF CONTROL COLUMN FORCES IN AIRCRAFT

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DEPARTMENT OF DEFENCE

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## SUMMARY

A device is described which is incorporated within a pilot's flying glove to measure forces exerted by the pilot on the control column of an aircraft during flight tests.

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## CONTENTS



## ANNEXES

# A DEVICE FOR MEASUREMENT OF CONTROL COLUMN FORCES IN AIRCRAFT

## 1. INTRODUCTION

1.1 Informal discussions within the Aircraft Research and Development Unit (ARDU) and the Advanced Engineering Laboratory proposed the manufacture of the prototype device described herein which is the subject of the Reference A patent action. The requirement was to replace existing subjective methods used by test pilots to estimate control column 'stick' force during evaluation manoeuvres with a quantitative force measurement determined independently of the aircraft being flown.

1.2 This resulted in the device described herein whereby control column ('stick') force is measured in engineering units by a differential arrangement of semiconductor strain-gauge pressure transducers incorporated within a pilot's flying glove and displayed on wrist-mounted or other conveniently located digital displays. The device is self-contained, being powered by conventional dry cell batteries contained within the cuff of the glove, and requires no interface with aircraft systems.

1.3 The unique nature of this concept appeared to warrant a Patent Application by the Commonwealth of Australia (provisional Patent Application No PF4452 of 16 June 1982).

1.4 Evaluation of a prototype device was carried out by a number of ARDU test pilots on a range of aircraft during 1980/81 and several resulting suggestions for improvement were incorporated. The prototype device, whilst practical and usable as an evaluation tool, is an interim design and further development is recommended.

1.5 Existing methods of control force measurement are:

a. subjective estimation by the pilot; and

b. measurement of control force by means of a hand-held spring balance attached to the control column.

More rigorous measurement is possible by:

c. post-flight measurement through a flight test instrumentation/analysis system (eg strain-gauged control column/Aircraft Flight Test Recording and Analysis System (AFTRAS)/'Quick-Look' Primary Analysis Processor (PAP), Reference B); and

d. real-time measurement by strain-gauged control column and transmission, together with other transducer test data, to a ground analysis station by means of a telemetry system.

1.6 Methods c and d apply to the case of engineering analysis of an instrumented flight test aircraft where the scale of the task warrants the expense of instrumentation, eg weapons clearance tests, aerodynamic flutter tests and, as such, are beyond the scope of the present report. In less comprehensive performance and handling assessments, known as Preview Tests, especially where the time available for test is limited, eg Reference C evaluation of an aircraft on a sales tour, a simple yet accurate device is highly desirable.

1.7 Subjective estimation of control forces by the pilot provides unsatisfactory estimation accuracies due to a pilot's judgement depending largely on his experience and currency in this type of testing. The use of a hand-held spring balance is both awkward and potentially hazardous, due to the extraneous equipment required to be handled, connected to the control column and/or stowed in the confines of the cockpit.

## 2. PURPOSE

2.1 The purpose of the device was to enable a test pilot to obtain regular measurements of instantaneous values of the force being applied at the hand grip of the control column during appropriate phases of aircraft performance and handling tests. By remembering, logging or orally recording such instantaneous values, together with simultaneous readings of the aircraft 'g' meter, the parameter 'stick force per g' can be derived for given manoeuvre conditions, eg speed and altitude. This parameter is especially valuable in assessing effectiveness of the aircraft control system interface with 'man-in-the-loop'. The concept of 'stick force per g' and its utility in flight test is discussed in Annex A.

## 3. DESCRIPTION OF THE DEVICE

3.1 Conceptual Design. The concept for the device was to incorporate two pressure pads within a pilot's flying glove arranged differentially to remove the squeezing effect of the pilot's hand on the control grip, thus measuring only the control force applied by the pilot.

3.1.1 Figure 3.1 depicts the force vectors measured by this means, ie forces applied to the control column in the longitudinal (forward and aft) and transverse (left and right) directions.

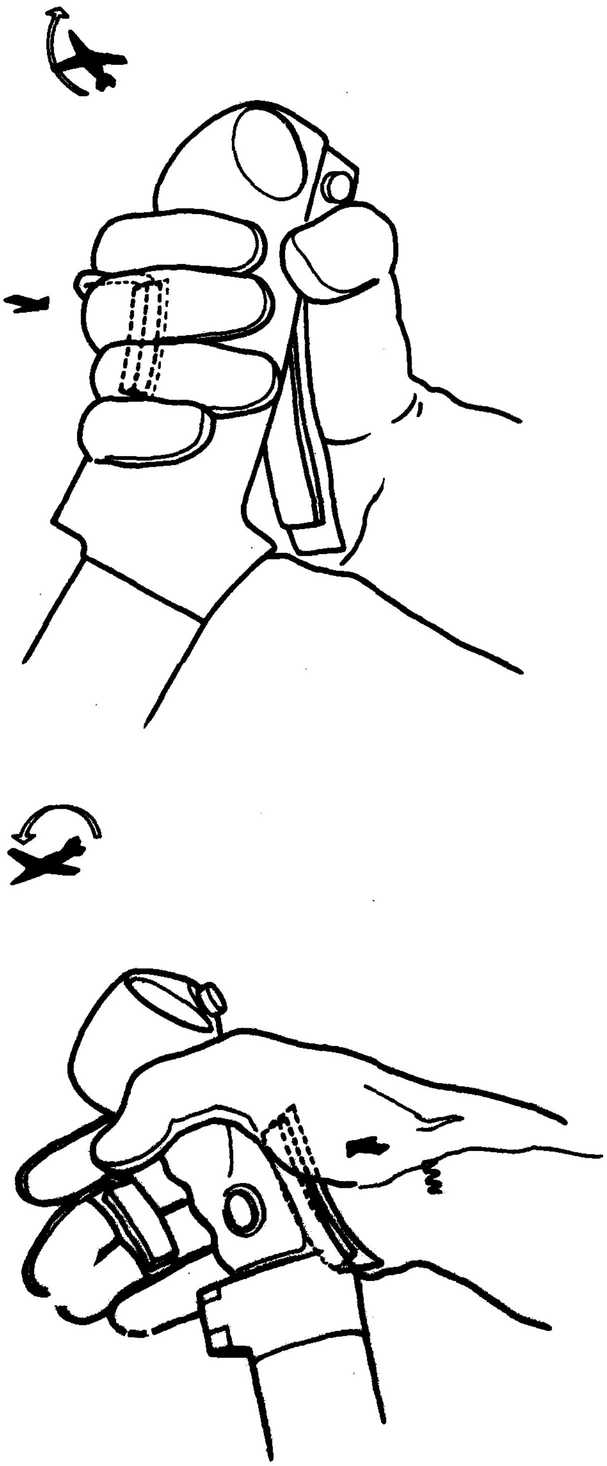

FIGURE 3.1.a - PRINCIPLE OF MEASUREMENT OF LONGITUDINAL
FORCE INPUT TO [illegible]

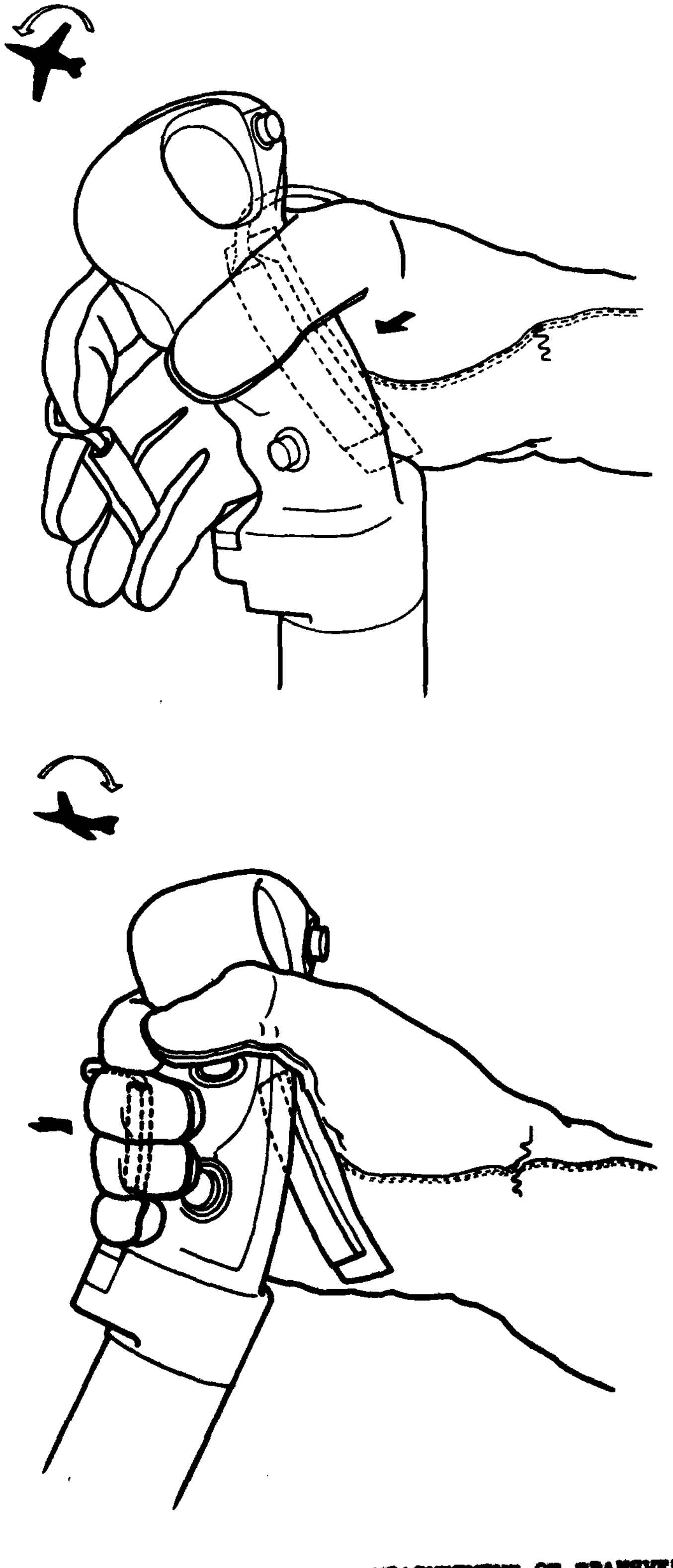

FIGURE 3.1.b - PRINCIPLE OF MEASUREMENT OF TRANSVERSE INPUT TO CONTROL COLUMN

3.1.2 Figures 3.2 to 3.4 show the arrangement of pressure pads on a right hand glove to achieve these measurements. One pressure pad is arranged to bridge across the two central fingers leaving the index finger and the little finger free to actuate intercom, trim and weapons release control and switches, whilst the other pad is arranged across the palm at the heel of the thumb. The central fingers apply pressure through the finger pad when pulling back on the control column and when pulling to the right and the palm applies pressure through the palm pad when pushing forward on the control column and when pushing to the left. In a roll manoeuvre, rotating the hand slightly in an anti-clockwise direction ensures that the pads are aligned along the sides of the handgrip and allows the finger pad to measure force applied towards the right and the palm pad to measure force applied to the left. Thus, the reaction of the hand controller on a pressure pad provides a measure of control pressure and, since a flat plate of known size (bearing area) is arranged to back each pressure pad, the resultant force acting in a direction normal to the pressure pad can be measured.

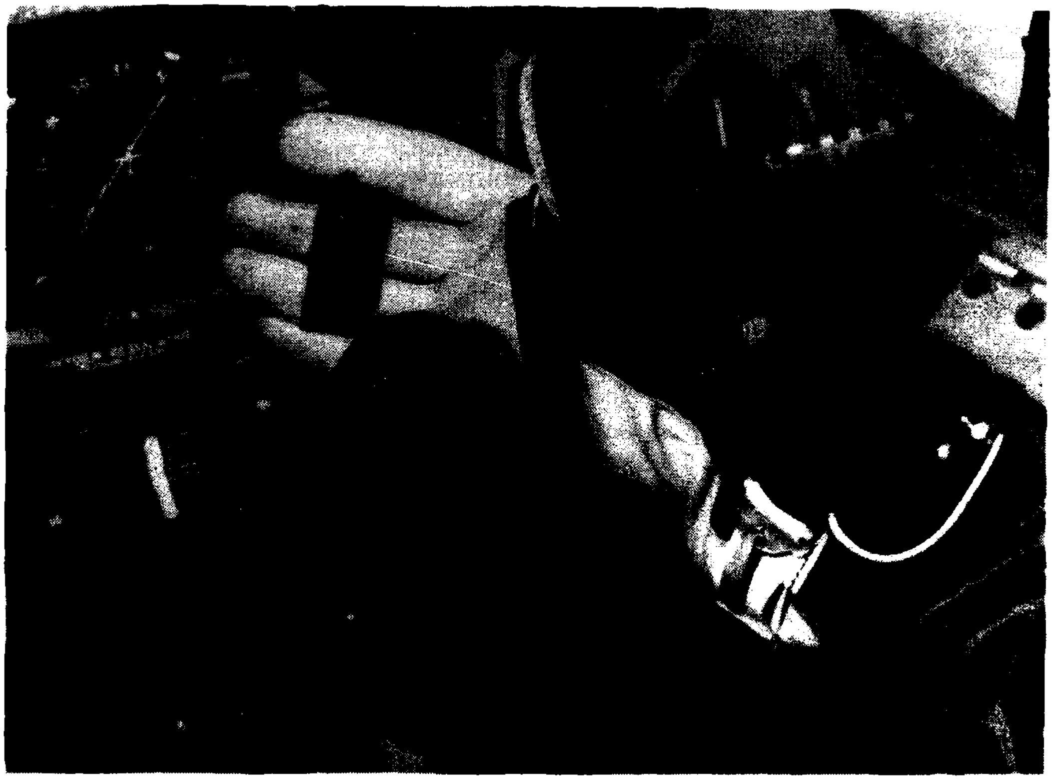

**FIGURE 3.2**

FIGURE 3.3 - ORIENTATION OF HAND ON CONTROL COLUMN FOR A TRANSVERSE (ROLL) INPUT

FIGURE 3.4 - ORIENTATION OF HAND ON CONTROL COLUMN FOR A FORE AND AFT (PITCH) INPUT

3.2 Mechanical Arrangement. An assembly drawing of the instrumented glove is shown in Annex B. The arrangement of pressure pads containing a silicone fluid is shown at AA (finger pads) and at BB (palm pad) together with display unit and electronics (force indicator) assembly on the outside of the glove with the battery pack mounted on the inside of the cuff.

3.3 Electronic Arrangement. The electronic arrangement is depicted in the circuit diagram of Annex C. Outputs from each of the two (different) National Semiconductor strain gauge pressure transducers LX1620G (finger pad) and LX1610G (palm pad) are fed separately through inverting offset amplifiers (nominal gain 0.5) and then scaled by variable gain inverting amplifier stages. Both signals are then fed to the differential input of an Intersil ICL 7106 digital voltmeter chip of 3½ digits capacity which provides a force difference measurement (ie eliminating squeeze effect) in engineering units at the liquid crystal display (LCD). Possible future improvements to this basic circuit include a 'battery-low' indicator and a peak force sample and hold facility.

## 4. UTILIZATION

4.1 Aircraft Types. The device as prototyped was intended for use in fixed wing aircraft having a control column with a hand control grip. Some examples in the RAAF inventory are:

Mirage
Macchi
Airtrainer
F-111C

4.1.1 The device may also have application to rotary wing aircraft such as:

Iroquois
Chinook
Bell 206B-1

for stability and ergonomic studies.

4.1.2 Newer aircraft having force-actuated rather than displacement-actuated controllers, such as F-16, should also be amenable to flight test evaluation through the use of this device for ergonomic studies. In these cases, as for the Mirage III, an additional display device can be mounted elsewhere as convenient for better visibility by the pilot (Annex D).

4.2 In-Flight Use. For any particular aircraft under flight test evaluation, the pressure pad orientation on the glove should be optimized by the pilot to ensure that:

a. there is adequate bearing area between the sensor pads and the hand grip when actuating the control in both longitudinal and transverse directions;

b. the sensor pads are oriented normal to these directions whilst the pilot's hand rests in a naturally comfortable unstrained position on the control grip; and

c. the pilot is able to actuate essential switches on the control grip conveniently whilst his hand is oriented for the necessary measurement function.

4.2.1 To this end, the pressure sensing pads are relocatable on velcro backing to allow alignment as required for a given pilot in a particular aircraft test.

4.2.2 The device, as prototyped, is not configured for use with wheel type controls but could be adapted to be so (ie tangential force clockwise and anti-clockwise, and push-pull force). Also a variation of the device could be incorporated within a pilot's flying boots for rudder pedal force measurement. Pressure pads mounted as appropriate under the soles of a pair of flying boots, for example by means of a light webbing harness or overboot, would enable left and right rudder pedal force to be measured and displayed or recorded as required.

## 5. CONCLUSIONS AND RECOMMENDATIONS

5.1 A device for measurement of control column forces in aircraft has been described which facilitates quantitative measurement of stick force and hence the derivation of the parameter 'stick force per g' during flight tests. This device is self-contained in a pilot's flying glove and represents a considerable advance over the previous preview technique of attaching a spring-balance to the control column in flight.

5.2 A prototype unit has been used at ARDU and further evaluation of the display is in progress to allow sampling and holding of peak force values experienced during a transient manoeuvre.

5.3 This device is patented by the Commonwealth of Australia (PF4452 of 16 June 1982).

## 6. ACKNOWLEDGEMENTS

6.1 The author wishes to acknowledge the assistance of FLTLT C.J. White, RAAF in the preparation of technical comments on the utility of measurements of control forces during flight test procedures and of SQNLDR A.A. Vilcins for his valuable suggestions during initial flight test evaluation of the prototype glove.

6.2 Also many thanks to co-inventors, Mr R.E. Clarke and Mr W.I. Menadue of the Advanced Engineering Laboratory, DRCS for their patience and ingenuity during the development phase.

## 7. PROJECT PERSONNEL

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| AEL Project Officers: | Mr W.I. Menadue, M.E. |
| | Mr R.E. Clarke |

## 8. REFERENCES

A. Australian Provisional Patent Application No PF4452 of 16 June 982, 'Flight Test Aid', G.A. Morgan, W.I. Menadue and R.E. Clarke

B. Department of Defence, RAAF Aircraft Research and Development Unit, 'Aircraft Flight Test Recording and Analysis System (AFTRAS)', ARDU Report No TI GEN 11, November 1977

C. Department of Defence, RAAF Aircraft Research and Development Unit, 'TURBO-MENTOR Preview Report', ARDU Report No TI [illegible], October 1976

# MEASUREMENT OF CONTROL FORCES IN AIRCRAFT FLIGHT TESTING

1. The measurement of control stick forces (longitudinal and lateral) in flight testing is undertaken for data analysis and specification compliance requirements of the following aircraft flying qualities:

   a. static longitudinal stability;

   b. manoeuvring longitudinal stability;

   c. lateral-directional static stability;

   d. handling under asymmetric power;

   e. stalls; and

   f. rolling performance.

1.1 Specification compliance is generally evaluated against FAR Part 23, MIL-F-8785C (ASG) and AvP970. The prime document for specification of military aircraft is MIL-F-8785C.

2. Static Longitudinal Stability. The variation of longitudinal control force (Fs) with airspeed about a force trim airspeed is indicative of the static longitudinal stability. Local stick force gradients are important for assessing an aircraft's handling qualities at or about various trimmed airspeeds. Plots of stick force vs airspeed, eg Figure 1, assist in assessing qualitatively the presence of force cues available to the pilot to indicate an 'off-trim' condition. Poor feedback/sensory cues are particularly important when the pilot's attention is taken away from the flight instruments, eg cruise - changing radio frequencies, checking map routes, landing - outside scan pattern during final approach, whilst heavy control forces give rise to a tendency to overcontrol and to pilot fatigue.

2.1 Section 3.2.1.1 of MIL-F-8785C is relevant to longitudinal static stability specification compliance.

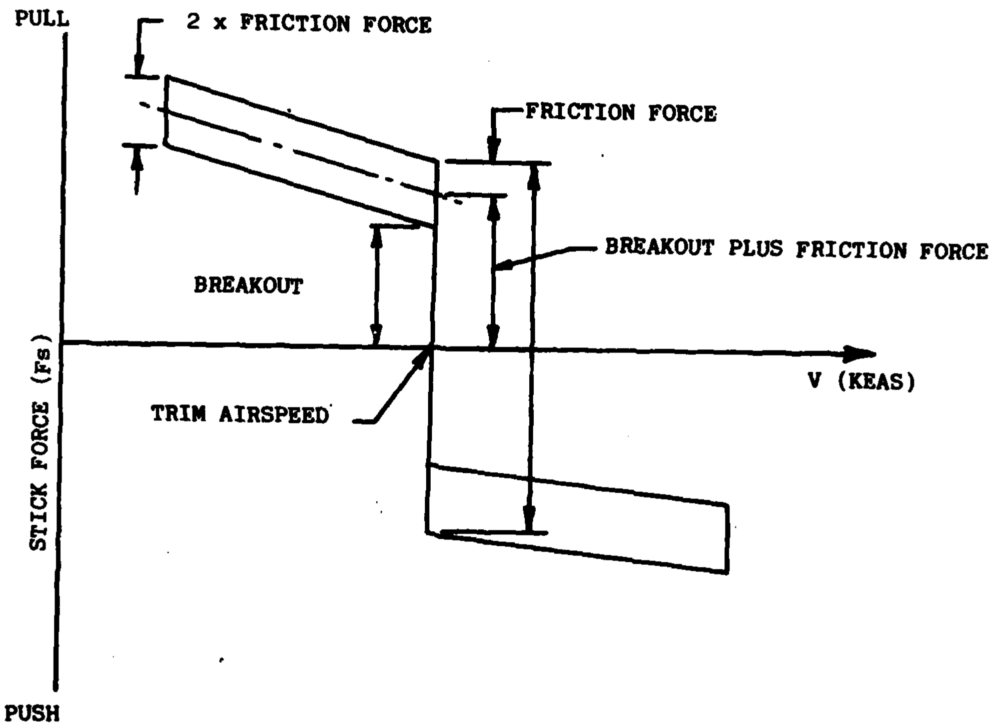



FIGURE 1 - STATIC LONGITUDINAL STABILITY - VARIATION OF LONGITUDINAL CONTROL FORCES WITH AIRSPEED ABOUT A TRIM AIRSPEED

3. Manoeuvring Longitudinal Stability. The longitudinal control force (Fs) variation with normal acceleration ($\ddot{n}$), or 'stick force per g' (Fs/g) eg Figure 2, is a primary 'control feel' parameter and is an indicator of longitudinal manoeuvring stability. The acceptability of a particular aircraft's 'stick force per g' will generally depend on at least the following considerations:

a. The amount of manoeuvring and the nature of the manoeuvring tasks required for mission accomplishment. If the aircraft is designed to be manoeuvred extensively, the gradient must be low enough so that the pilot is not fatigued excessively. However, the gradient must not be too low or the control feel may be too light and sensitive. Additionally, there may also be inadequate protection against inadvertent overstress with a low force gradient.

b. The limited load factor or 'g tolerance' of the aircraft. Obviously the Fs/g must be high enough to discourage inadvertent overstress. Gradients must be higher for aircraft with low g tolerances than for aircraft with high levels. The pilot rightly expects untrimmed stick forces to be high when the aircraft is manoeuvred near its limit load factor.

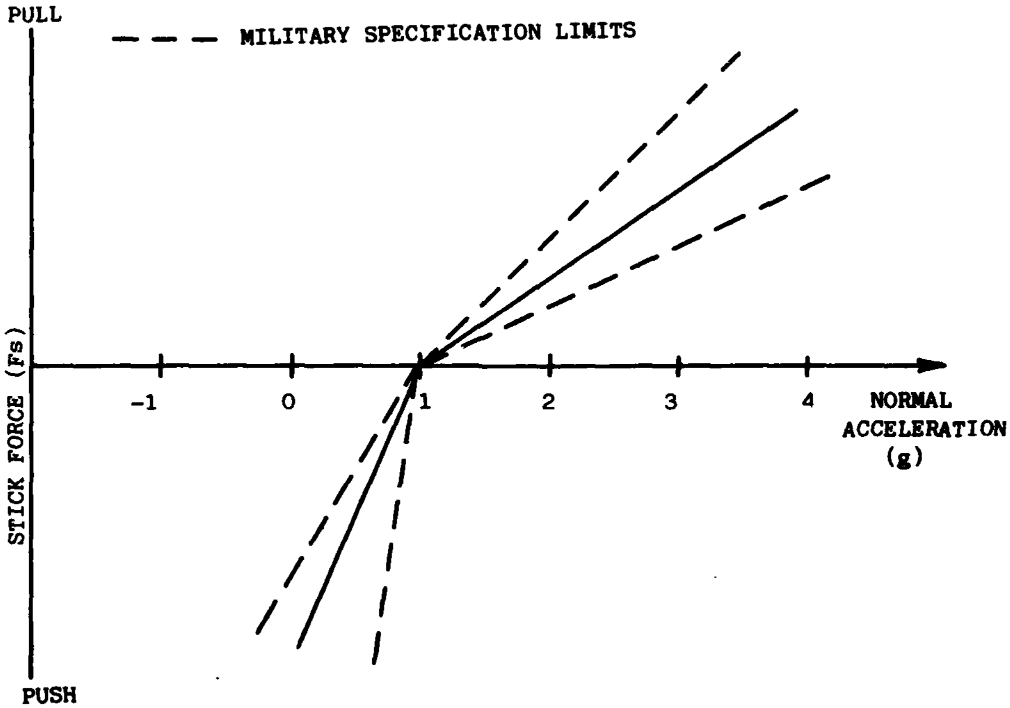



FIGURE 2 - LONGITUDINAL MANOEUVRING STABILITY - VARIATION OF LONGITUDINAL CONTROL FORCE WITH NORMAL ACCELERATION OR 'STICK FORCE PER G'

3.1 It is very desirable that the plots of longitudinal control force versus normal acceleration be linear within the range of normal accelerations which would normally be attained during manoeuvring tasks in operational use. Some non-linearity must be expected in all aircraft; however, the departure from linearity should be gradual.

3.2 If the variation of normal load factor with angle-of-attack is linear ($n/\alpha$), applicable specification limits for the local Fs/g gradient can be plotted on the longitudinal control force curves as an aid in determining specification compliance. The relevant sections of MIL-F-8785C are 3.2.2.2 and 3.2.2.2.1 (including Table 5).

4. Lateral-Directional Static Stability. Lateral-directional static stability characteristics are quantified by conducting a number of steady heading side-slips. Aileron force, Fa (lateral control force) variation with side-slip angle $\beta$, sometimes referred to as apparent dihedral effect, ($C_{\ell\beta}$), has a major influence on lateral-directional trimability and the ease with which the pilot can control bank angle with rudder inputs, eg Figure 3. If the variation is negative such that left lateral control force is required in left side-slips, and vice versa, the stability derivative, $C_{\ell\beta}$, is known to exhibit a negative sign. This results in positive dihedral effect, ie the aircraft tends to roll opposite to the induced side-slip. Some degree of positive dihedral effect is desirable for satisfactory lateral-directional flying qualities; however, it should not be so strong as to require excessive aileron force or deflection to control bank angle in side-slips. In addition, the variation of Fa with $\beta$ should be essentially linear. Relevant sections of MIL-F-8785C are 3.2.3.7, 3.3.6, 3.3.6.3, 3.3.6.3.1 and 3.3.6.3.2.

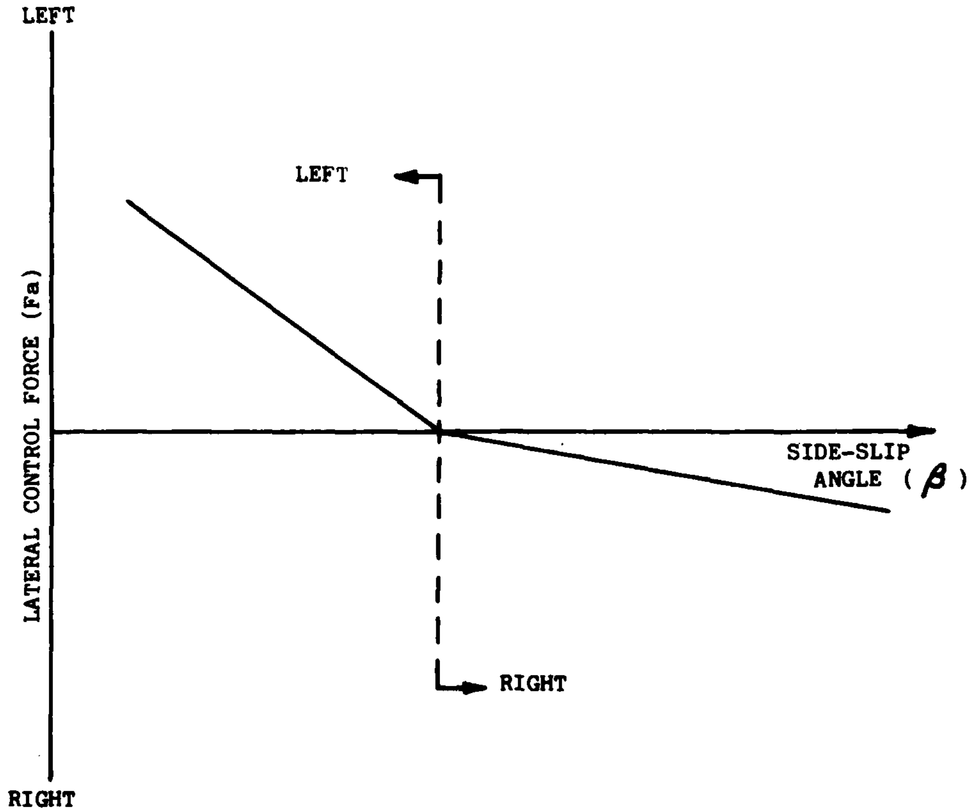



FIGURE 3 - LATERAL-DIRECTIONAL STATIC STABILITY - AILERON FORCE (LATERAL CONTROL FORCE) VARIATION WITH SIDE-SLIP ANGLE (APPARENT DIHEDRAL EFFECT ($C_{l\beta}$))

5. Asymmetric Power. Lateral and longitudinal control forces are measured during asymmetric power testing for the purposes of complementing the qualitative assessment of an aircraft's handling qualities after a loss of thrust condition. They are also analysed for specification compliance, the relevant sections of MIL-F-8785C being 3.2.3.7, 3.3.9.1, 3.3.9.2 and 3.3.9.4.

6. Stalls. In stall testing, it is important to quantify the stick forces experienced by the pilot during stall approach, stall, and stall recovery. During testing, the aircraft is trimmed at a speed somewhere above the expected stall speed (usually 1.2 to 1.4 Vs) and decelerated slowly. By measuring the longitudinal stick forces during the various phases of the stall the physical cues for an impending stalled condition can be defined.

7. Rolling Performance. In determining the rolling performance of an aircraft (generally the time to roll through a given bank angle change), roll control forces are measured for specification compliance. Section 3.3.4.3 of MIL-F-8785C assigns maximum and minimum limits to the control forces associated with meeting certain levels of roll performance (depending on aircraft role). Lateral control forces required to obtain the rolling performance necessary for various mission tasks should be comfortable for the pilot. Forces of too large or too small a magnitude cause objectionable sluggishness or sensitivity in response to small lateral control inputs. The maximum and minimum forces which are acceptable in any aircraft depend on the mission of the aircraft. In general, lower lateral control forces are desirable for high manoeuvrability aircraft. If the aircraft is equipped with a wheel or yoke type cockpit controller, higher lateral control forces may be accepted since the pilot is able to apply both hands, thus larger forces, to the control.

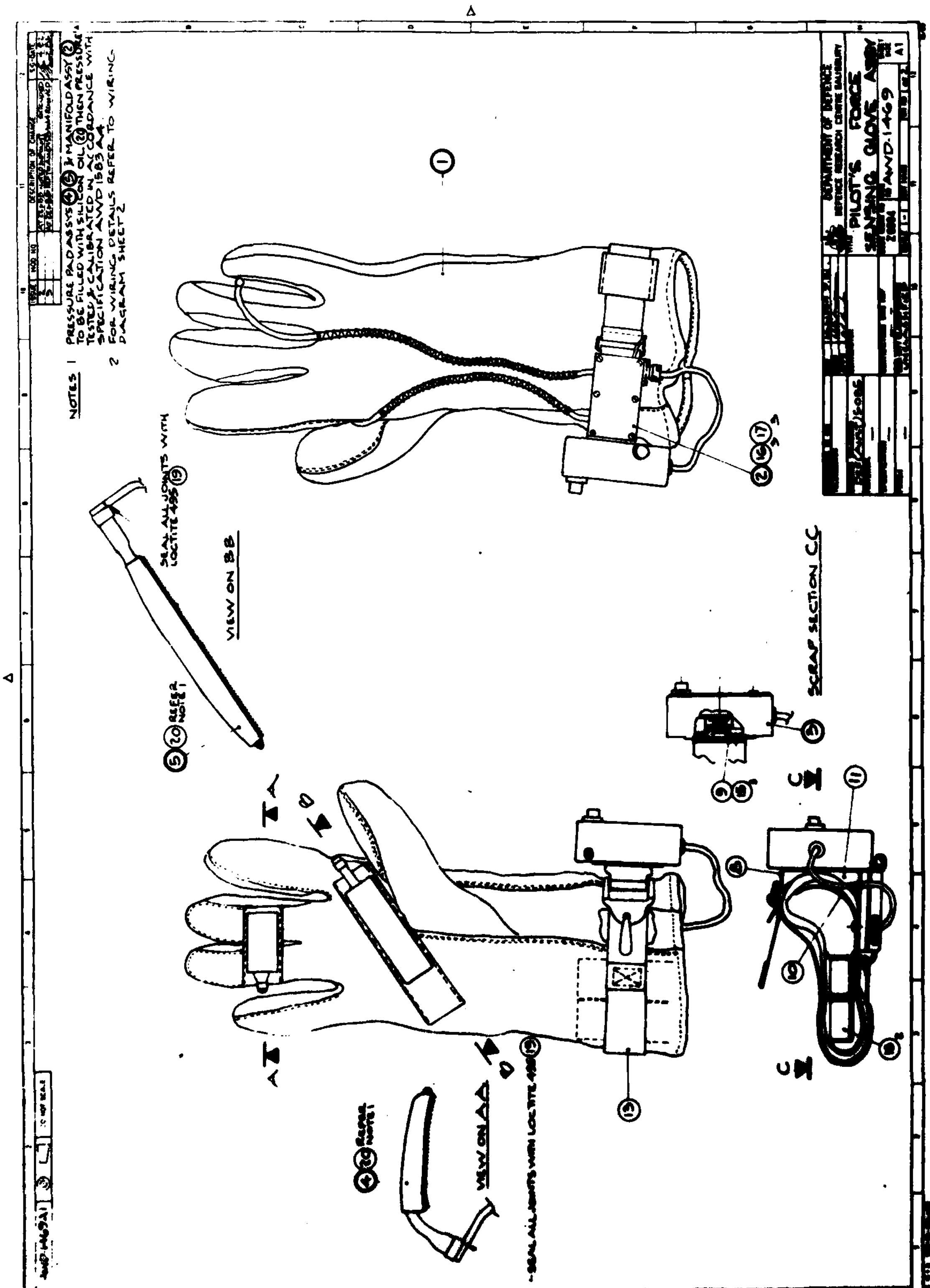
7.1 The measurment of usable lateral control force data during rolling manoeuvres is difficult unless automatic recording devices are available. The hand-held force gauge (traditional equipment) is usually too cumbersome and annoying to utilize for in-flight measurements. The preview test aid would not be subject to this problem; however, the read-out may tend to indicate the transient lateral force applied during the sharp control input instead of the steady state control force of interest, depending on display integration times chosen.

8. Miscellaneous. Longitudinal control forces are measured in a number of other flight phases for the purpose of specification compliance. These areas relate to take-off, landing, dives, side-slips and cross-wind landings. The relevant sections of MIL-F-8785C are 3.2.3.4.1, 3.2.3.5, 3.2.3.6, 3.2.3.7 and 3.2.3.3.2.

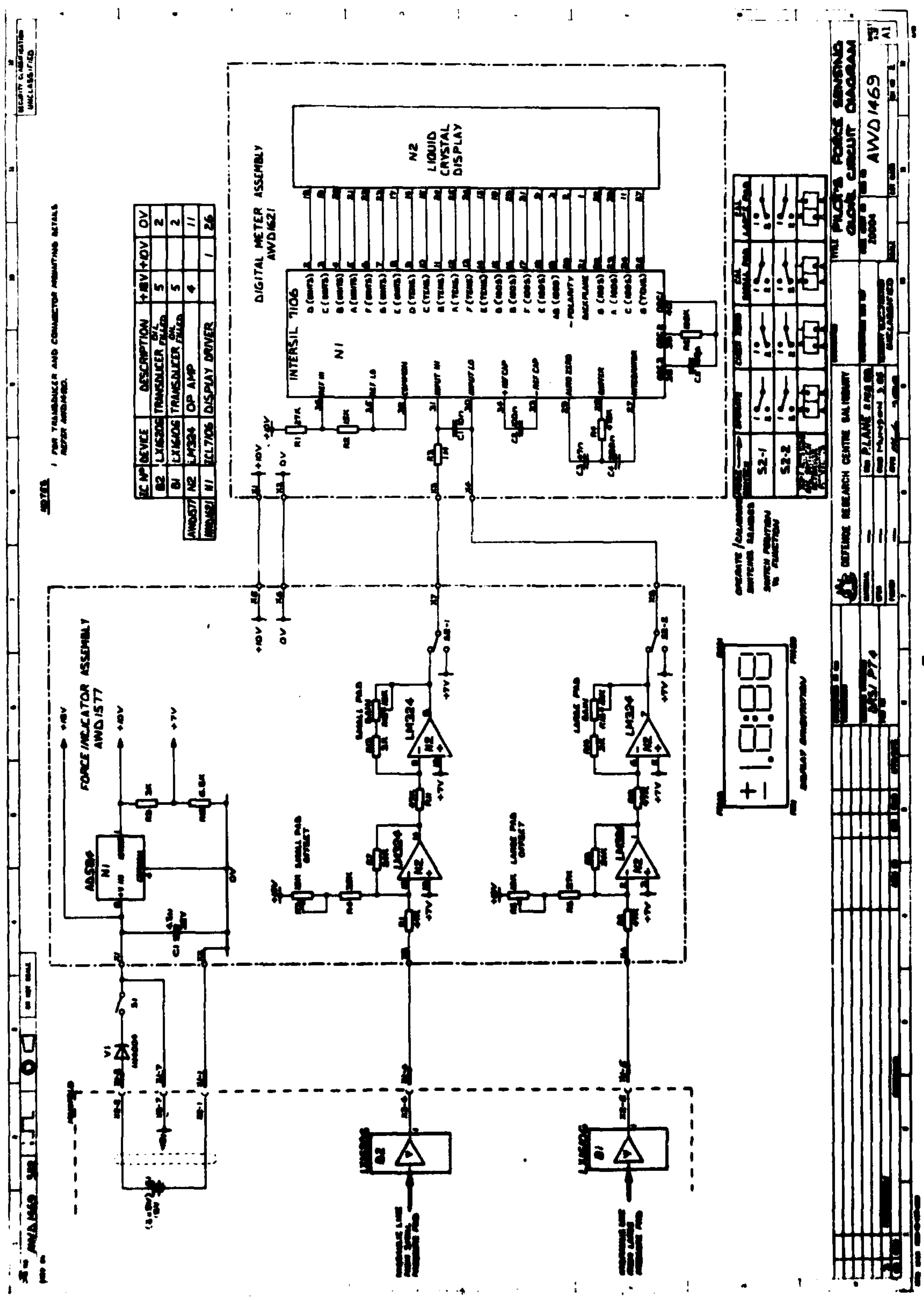
9. Comment. From the preceding presentation, there are a number of areas of aircraft flying qualities assessment that require the measurement of control forces (either longitudinal or lateral). A control force measuring device such as that described provides the test pilot with a comfortable piece of equipment with which to obtain accurate data for quantitative analysis of aircraft stability characteristics.

9.1 As tests for aircraft stability and control involve dynamic manoeuvres, it is desirable that a peak value recording mechanism be incorporated. This would reduce the pilot's workload during manoeuvre stability and roll performance testing.

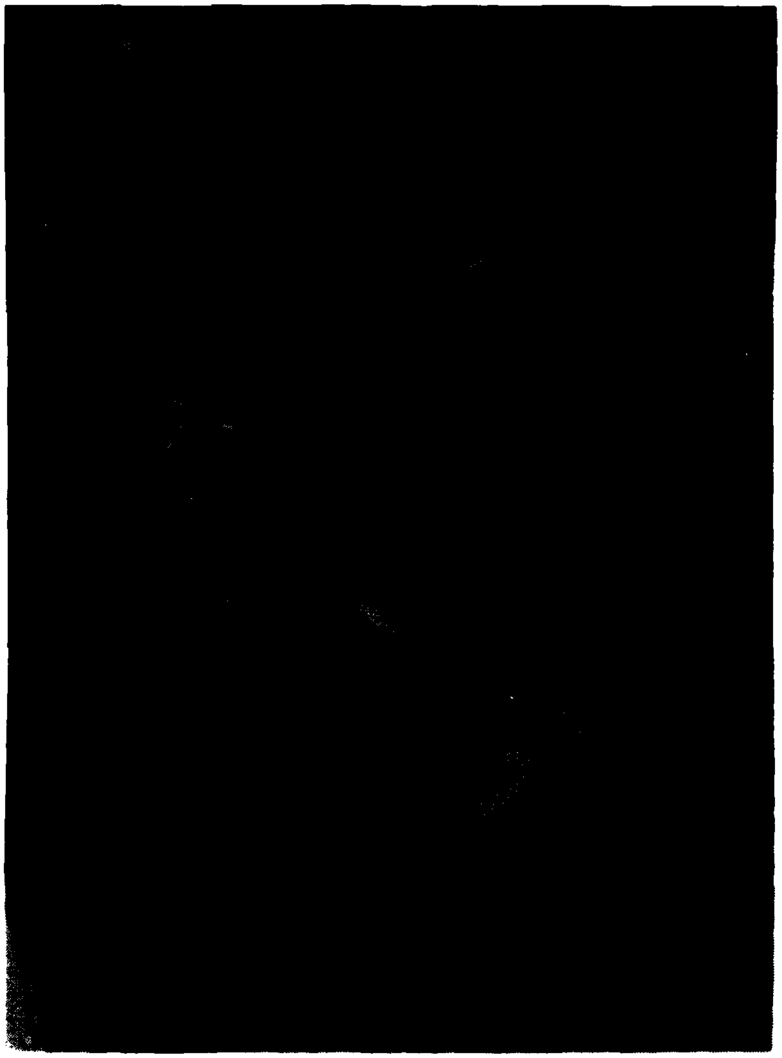
## PILOT'S FORCE SENSING GLOVE ASSEMBLY



CIRCUIT DIAGRAM - PILOT'S FORCE SENSING GLOVE



ALTERNATIVE MOUNTING OF FORCE INDICATOR



NOTE: This position for the display was requested by Mirage pilots as their view of the wrist-mounted display was obscured by the oxygen mask, the control column handgrip being lower and closer to the body in that aircraft than in the Macchi.

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